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Origin and Development of Zooplankton and Macrozoobenthos Communities in the Primary Succession of a Temporarily Anthropogenically Regulated Artificial Lake

Pencho Ivanov*

IBER, BAS, Sofia, Bulgaria

***Corresponding Author:** Pencho Ivanov, IBER, BAS, Sofia, Bulgaria.

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Abstract

The objective of this research is to observe the emergence and development of zooplankton and macrozoobenthos communities in an artificial water body under anthropogenically controlled hydrological conditions. The study of colonization and community formation in temporary water bodies provides insights into the factors and processes influencing the establishment of animal communities. These investigations are particularly relevant in the context of climate change, which significantly increases the number of desiccating water bodies that undergo recolonization upon each refilling event.

This research specifically focuses on the emergence and development of zooplankton and macrozoobenthos communities. The study site is Lake Ariana, located in central Sofia, Bulgaria. Zooplankton and macrozoobenthos samples were taxonomically identified and statistically analyzed. The absence of predatory pressure and stable environmental conditions, maintained by the lake's flow-through nature, facilitate the emergence and development of a viable zooplankton community. This community serves as a primary factor in ecosystem functioning. The macrozoobenthos fails to establish a stable community and is predominantly represented by Chironomidae. Varying conditions during lake filling events suggest different structures of the zooplankton community.

Keywords: Zooplankton, Macrozoobenthos, Artificial Pond, Primary Succession, Temporary Lake, Origin and Development, Community

Introduction

Temporary water bodies are globally widespread and their prevalence is increasing with climate change, consequently enhancing their significance for biodiversity [1]. A seasonally managed artificial lake under anthropogenic control provides an opportunity to monitor colonization patterns and evaluate the role of its faunal communities. This contributes to an enhanced understanding of faunal community formation processes in temporary water bodies. Temporary lakes can maintain high species richness due to their substantial variability in volume and persistence duration, occasionally rendering them biodiversity [2,3]. Consequently, these systems have attracted attention in biodiversity conservation programs [4].

Zooplankton communities are vital components of biodiversity in freshwater ecosystems, and the study of their formation mechanisms is a key topic in freshwater ecology research. Copepods constitute the primary representatives of the zooplankton community in these lakes. Different species exhibit preferences regarding the duration of the aquatic phase, establishing them as crucial ecosystem components and indicators of hydroperiod (HP) length [5]. In natural basins, species richness correlates with HP duration and lake age, as well as predatory pressure [6-9].

The present investigation aims to characterize the origin and development of zooplankton and macrozoobenthos communities in the artificial Lake Ariana. The focus is on community structure, expressed through species composition and colonization periodicity [1]. Additionally, factors influencing faunal community formation under anthropogenically regulated environmental conditions are investigated. The regulation of the lake's hydrological regime through its flow-through nature exerts significant influence on the structuring of zooplankton and macrozoobenthos communities.

Material and Methods

Lake Ariana (ARI) is located in the lower part of Borisova Gradina (42°41′22″N, 23°20′12″E) in Sofia City, at an elevation of 550 m a.s.l. It is an artificial flow-through lake with a surface area of 1.3 ha and a concrete base and walls and a depth of 0.80 m. Lake Ariana is filled annually by a borehole at the end of May or the beginning of June and drained in September into the nearby Perlovska River. Each spring, before refilling, it is cleaned of deposits and dirt.

Figure 1: Lake Ariana Full (Top) And Empty (Bottom)

Water temperature (°C) (TWAT), dissolved oxygen content (mg.dm^{-3}) (O2) and oxygen saturation (%) (OXYD); active reaction (pH) and electrical conductivity (μS.dm^{-3}) (COND), were measured in situ using a WTW Multi 1975i multi-parameter system. Transparency was assessed using a Secchi disk (m) (TRAN). Based on the average depth and area, the water volume (m^3) (WVOL) was calculated. The recorded nutrients included nitrate-nitrogen (NO_3), phosphates (PPHO), total nitrogen (TN) and total phosphorus (TP). Their concentrations were measured photometrically using a WTW PhotoFlex portable photometer.

The plankton samples were collected by filtering a volume of 100 dm^3 of water through Apstein plankton net with a 55μm mesh size. Two samples were collected from 2013, three from 2014, and six from 2015. The samples were brought to a working volume of 0.1 dm^3 and processed in the laboratory. Quantitative processing involved counting the organisms in 0.01 dm^3 within a Bogorov chamber at 16x magnification under a stereomicroscope. The entire volume of the samples was checked for taxa with lower densities. An Olympus BX5 compound microscope was used to identify the genus and species. The abundance was expressed in ind.m^{-3}. Taxonomic identification was performed according to [10].

The MZB samples were collected according to EN ISO 9391:1995; EN 28265:1994; EN 27828:1994 standards. The laboratory processing of the MZB materials included sorting samples by weeks, months, and years and taxonomic determination on an MBS-9 stereomicroscope. Taxonomic determination of benthos was done after 10]. The current systematic status of the organisms is consistent with Taxonomic hierarchy ver. 4.1. Taxonomic determination of Cladocera was done according to [10,11].

Excel 2019 was used to visualize settlement dynamics and relative abundances of different taxonomic groups.

Geometric Curves of Abundance – A graphical representation of the number of taxa categorized by different abundance levels [12]. The interpretation is based on the principle that in undisturbed or relatively less impacted sites, the number of low-abundance taxa is high.

K (Abundance-Biomass Comparison) Curves of Abundance and – A method used to compare the distribution of numerical abundance and biomass among taxa to assess ecological conditions [13]. In k-dominance curves the cumulative relative abundances of species, ranked in decreasing order of their importance in terms of abundance (or biomass), are plotted against species rank, or more usually log species rank. The higher the curve in a k-dominance plot, and the more quickly it reaches its maximum value (of 100), the lower the evenness and richness components of diversity.

Diversity indices (Shannon, Margalef, Pielou, and Simpson) were calculated using PRIMER 6 & PERMANOVA+.

Trophic interactions were modelled using Loop Analysis (LA) through PowerPlay software from Oregon State University. This approach classifies interactions using symbols {-, 0, +} to construct a community matrix and assess ecosystem stability via polynomial equations solved using the Euclidean algorithm and the Routh-Hurwitz theorem.

Results

The stable physicochemical conditions of the lake, maintained by its flow-through nature, led to small fluctuations in different years, influenced mainly by atmospheric conditions (Table 1).

DATE	TWAT [C]	O2 [mg.dm^{-3}]	OXYD [%]	COND [µS.dm^{-3}]	pH	TN [mg.dm^{-3}]	TP [mg.dm^{-3}]	PPHO [mg.dm^{-3}]	NO_3 [mg.dm^{-3}]
30 May 13	20,00	9,28	114,00	718,00	7,98	7,00	0,12	0,19	1,00
04 July 13	21,70	7,34	88,00	351,00	7,34	7,00	0,42	0,97	3,00
10 June 14	24,60	6,31	82,30	302,00	8,48	7,00	0,18	0,75	5,00
09 July 14	25,00	6,60	85,70	351,00	7,34	4,20	0,58	0,94	5,00
11 Aug 14	25,20	6,90	89,00	377,00	7,76	1,40	0,63	1,13	6,00
27 May 15	20,30	10,16	126,10	352,00	7,36	6,30	0,92	1,51	5,00
09 June 15	22,90	9,57	128,00	395,00	7,56	5,80	0,74	1,41	5,00
23 June 15	23,00	10,68	135,10	418,00	7,73	6,40	1,48	1,09	4,00
07 July 15	27,00	7,20	100,10	394,00	8,49	6,60	1,14	1,97	3,00
21 July 15	27,00	8,85	108,80	391,00	8,55	5,00	1,17	1,48	5,00
04 Aug 15	26,50	8,31	117,40	394,00	8,17	3,40	1,19	0,99	6,00

Table 1: Values Of Measured Physicochemical Parameters and Biogenic Elements in Lake Ariana in 2013 – 2015.

Zooplankton Community Structure

Over three years, 24 zooplankton taxa were identified: 10 in 2013, 9 in 2014, and 15 in 2015 (Table 2). Cyclopoid copepods were the dominant taxa, followed by cladocerans and rotifers, whereas calanoid copepods were infrequently observed.

In 2013 and 2015, cyclopoid copepods initially dominated (95% and 60%, respectively) (Figure 2). However, in 2014, rotifers were the initial dominant group (97%), followed by cladocerans (80%), with copepods remaining a minor fraction.

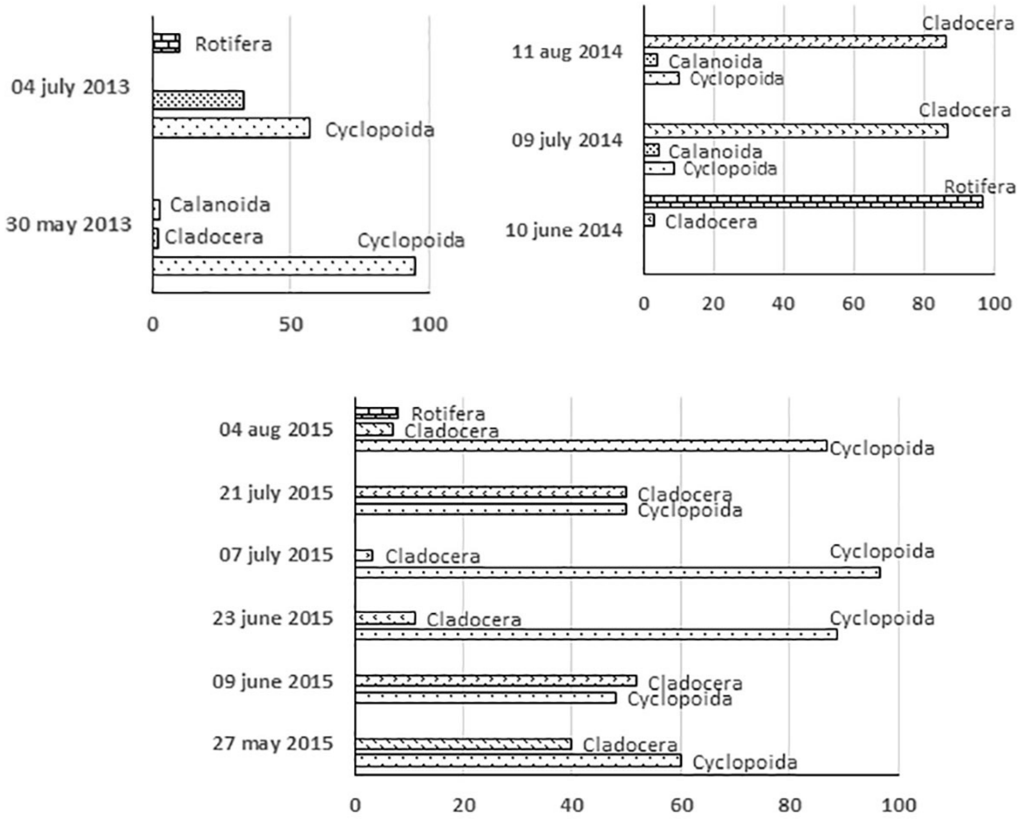

Figure 2: Sequence Of Settlement and Relative Share of The Abundance of Individual Taxa of The Zooplankton Community in Lake Ariana in 2013-2015.

Key species included Acanthocyclops robustus (Sars, 1863) in 2013 and Thermocyclops dybowskii (Landé, 1890) in 2015, both typical of shallow lakes. They are characteristic of reservoirs with active reaction values of about 7, which probably explains their significant presence in the first stages of the hydroperiod during these two years [14,15]. Cladocerans, mainly Daphnia longispina (Müller, 1776) and Scapholeberis kingi (Sars, 1888), exhibited rapid growth and adaptability. Both species are characteristic of small lakes, fast-growing, and unpretentious to the number of electrolytes in the water, especially Scapholeberis kingi [16,17]. Rotifers were represented primarily by Lecane, Brachionus, and Platiyas genera. The 2014 community was unique, with Euchlanis and Trichotria rotifers dominating (96%), along with cladocerans D. longispina and Moina rectirostris. In the later stages, Simocephalus vetulus (Müller, 1776) also appeared, which is characteristic of newly formed reservoirs [18].

The geometric curves of abundance (Figure 3) indicate a relatively even distribution of a small number of rare species, with only two to three taxa exhibiting peak abundance. This pattern is particularly pronounced in 2013, although it is likely influenced by the limited number of samples collected (only two).

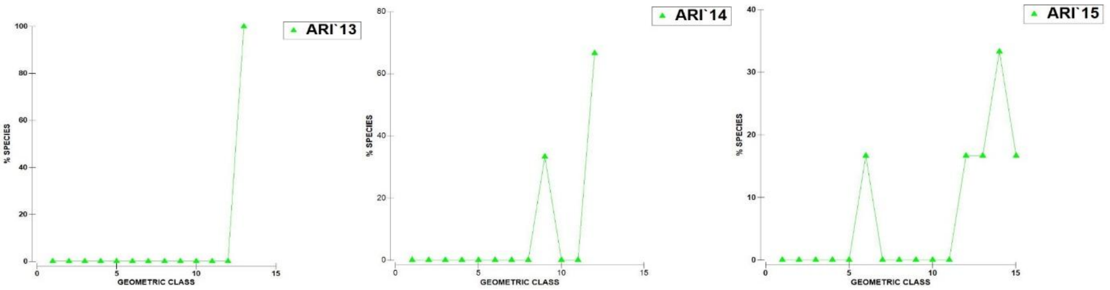

Figure 3: Geometric Curves of Zooplankton Abundance in Lake Ariana 2013 – 2015

The K-dominant abundance and biomass curves in Lake Ariana (Figure 4), as an indicator of the presence of stress in the system and/or poor ecological conditions, in this case reflect a small number of taxa and their high abundance. The rapidity of the curve does not reach 100 indicates a low evenness of the distribution of taxa and a low degree of species richness. The Warwick coefficient (W) is also very low, which is an indicator of stress in the message.

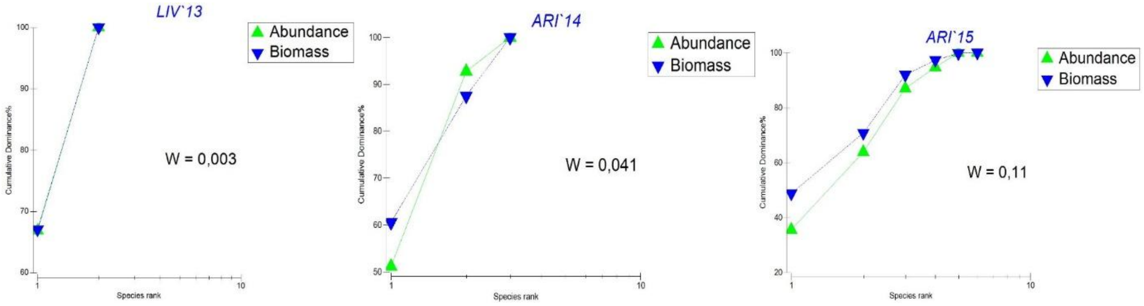

Figure 4: K-Dominant Curves of Zooplankton Abundance and Biomass in Lake Ariana 2013 – 2015 And Warwick Coefficient (W).

In 2013, the zooplankton biomass in Ariana Lake was dominated by Daphnia longispina (36%), with Acanthocyclops robustus as a co-dominant species (17%). Nauplii and juvenile cyclopoids accounted for 11% each. Subdominant species included Simocephalus vetulus (9%), Chidorus sphaericus (Leach, 1816) (7%), Alona rectangula (Sars, 1862) (5%), and members of the genus Alonella (3%).

In 2014, Simocephalus vetulus became the dominant species, constituting 51% of the plankton biomass, followed by Daphnia longispina (29%) and Acanthocyclops robustus (12%). Chidorus sphaericus was the only subdominant species (5%).

In 2015, Acanthocyclops robustus dominated the biomass (44%), along with juvenile cyclopoids (14%). Subdominant species included Scapholeberis kingi (8%), Thermocyclops dybowskii and Daphnia longispina (7% each), Eubosmina lamellata (6%), juvenile representatives of the genus Daphnia (5%), Chidorus sphaericus (3%), and Ceriodaphnia reticulata (Jurine, 1820), Simocephalus vetulus, and Alona rectangula (2% each).

Overall, both taxonomic abundance and biomass distribution appear relatively balanced. However, the uneven distribution of dominant taxa in terms of abundance compared to biomass is the primary factor contributing to the low values of the Warwick index.

Over the three years of study, the Shannon & Weaver diversity index (H) exhibited high values (Figure 5), which can be attributed to low population densities and high evenness. This pattern is further supported by the Pielou evenness index

(J), which also displayed high values.

Figure 5: Values Of Shannon & Weaver's Species Diversity Indices (H`), Margalef's Total Species Richness (D), Pielou's Evenness (J) And Simpson's Dominance (C) For the Zooplankton Community in Lake Ariana in 2013 – 2015

The Margalef species richness index - d (Figure 5) which accounts for the relationship between species number and the number of individuals per species, confirmed the low overall species richness, with a relatively even distribution of individuals among species. Consequently, this led to low dominance values as indicated by the Simpson dominance index (c).

In 2015, the values of H and d were slightly higher, likely due to the greater number of samples collected that year. Overall, the indices suggest favorable conditions for the development of the zooplankton community.

Macrozoobenthos Community Structure

Over three years, 23 MZB taxa were identified: 13 in 2013, 11 in 2014, and 14 in 2015. Chironomidae were consistently dominant (Figure 6.). In 2013, chironomids constituted 76% of MZB, retaining dominance throughout. Two species from the subclass Oligochaeta complete the composition of the community - Nais communis (Piguet, 1906) and Nais pardalis (Piguet, 1906). In 2014, chironomids initially comprised 100% of MZB, with Hemiptera, Ephemeroptera, and Odonata appearing later but remaining scarce. In 2015, chironomids again dominated initially, with Hemiptera and Ephemeroptera briefly increasing to 52% and 30%, respectively, before chironomids reasserted dominance. Chironomids are represented by the species Cricotopus sylvestris (Fabricius, 1794), Chironomus riparius (Meigen, 1804), Tanytarsus gregarious (Kieffer, 1909) and Cryptochironomus defectus (Kieffer, 1913). Ephemeropetra - Cloeon dipterum (Linnaeus, 1761), Odonata – family Libellulidae, Hemiptera – family Corixidae.

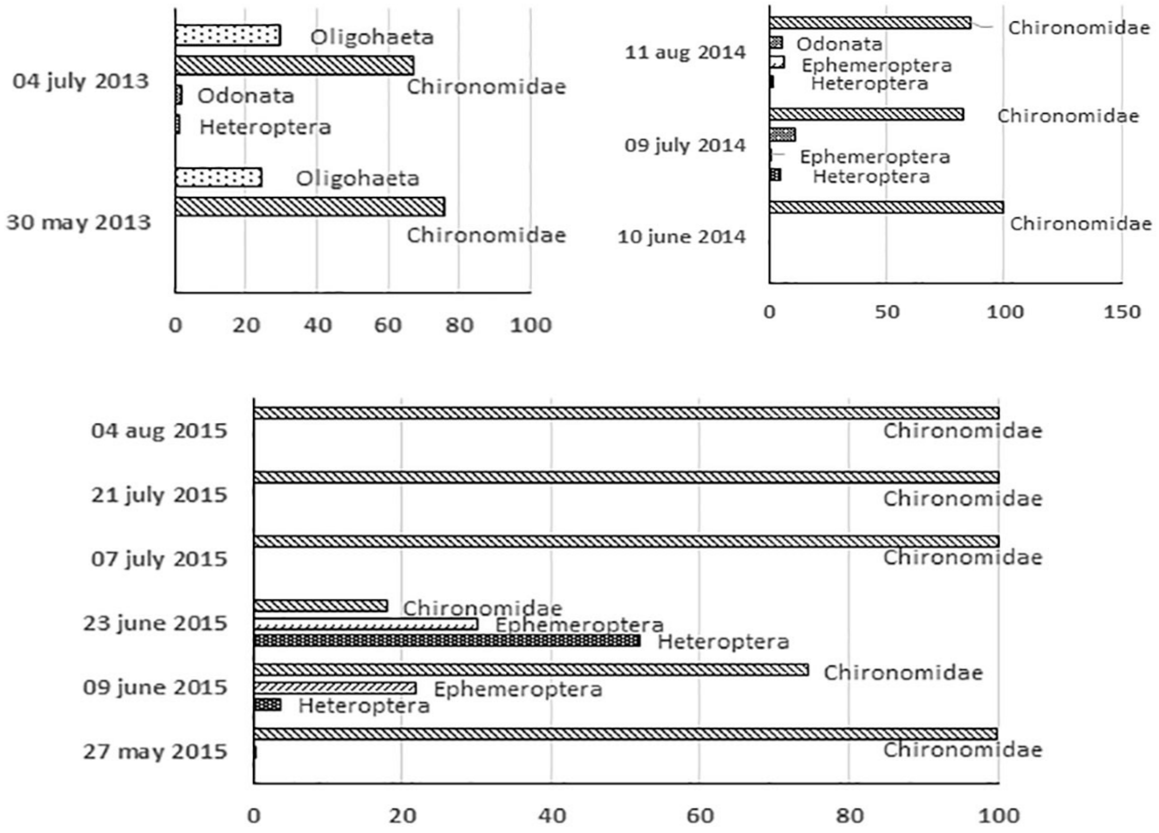

Figure 6: Sequence Of Settlement and Relative Share of The Abundance of Individual Taxa of The Mzb Community In Lake Ariana in 2013-2015.

Here, as in the zooplankton community, the values of the Shannon and Margalef indices (Figure 7) reflect the low number of individuals and the few species with even abundance. Accordingly, a relatively high evenness according to the Pielou index (J) and a low value of the Simpson dominance index (c).

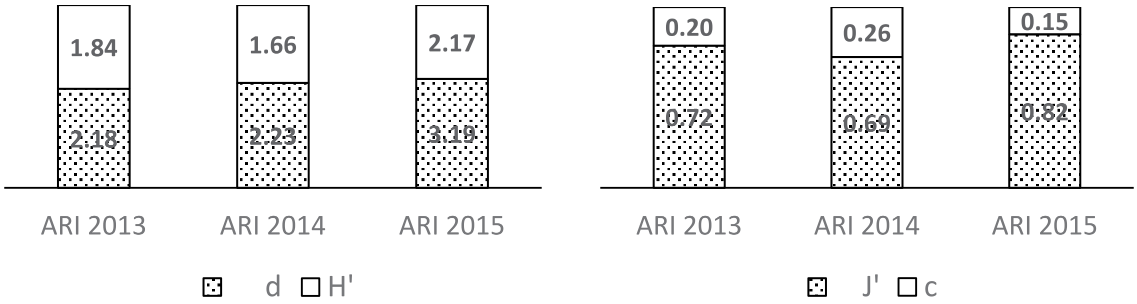

Figure 7: Values Of Shannon & Weaver's Species Diversity Indices (H`), Margalef's Total Species Richness (D), Pielou's Evenness (J) And Simpson's Dominance (C) For the Mzb Community in Lake Ariana in 2013 – 2015.

Trophic Structure of Zooplankton

The zooplankton community in Lake Ariana exhibited four functional trophic groups across all three study years: omnivores (Omni), phytoplanktonophages (PHph), detritophages (DF), and predators (PR) (Figure 8).

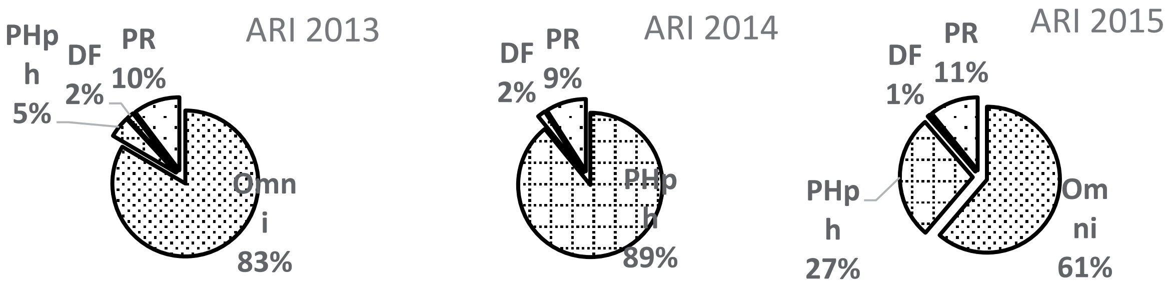

Figure 8: Percentage Ratios of The Abundances Per Ind.M-3 Of Individual Trophic Groups in The Composition of Zooplankton in Lake Ariana in 2013-2015. Legend: Omni – Omnivores; Phph – Phytoplanktonophages; Df – Detritophages; Pr – Predators.

In 2013 and 2015, omnivores dominated throughout the study period, whereas phytoplanktonophages had a more modest presence, peaking at 27% in 2015. In contrast, 2014 saw a dominance of phytoplanktonophages, which constituted nearly 90% of the community. Detritophages emerged in the middle of the hydroperiod (HP), accounting for an 8% share. Predators maintained a relatively stable presence of approximately 9–11% across all three years.

Trophic Structure of Macrozoobenthos

Each year, macrozoobenthic settlement in Lake Ariana begins anew due to the complete absence of deposited organic matter. All benthic organisms originate from external colonization, with community structure determined by the lake's environmental state. Three functional trophic groups were identified: scrapers (SC), deposit feeders (DF), and predators (PR) (Figure 9).

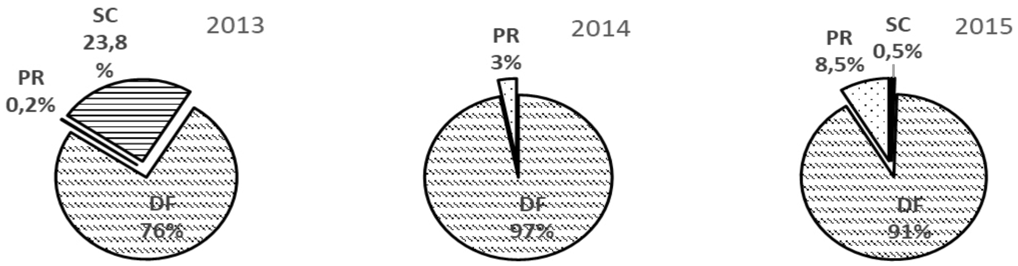

Figure 9: Percentage Ratios of The Abundance Per M2 Of Individual Ftgs in The Composition of The Zoobenthos in Lake Ariana In 2013-2015. Legend: Sc – Scrapers; Df – Detritophages; Pr – Predators.

Detritophages were consistently the dominant trophic group throughout the study period. Scrapers exhibited a comparatively significant presence only in 2013, comprising nearly 24% of the macrozoobenthic community. Predators remained underrepresented, reaching a maximum of 8.5% in 2015.

Loop analysis revealed that the Hurwitz coefficient for the zooplankton community was positive (a>0), indicating a stable system. Conversely, the benthic community was characterized by a negative coefficient (a<0), signifying instability. These results suggest that the ecosystem primarily functions within the pelagic zone, with plankton playing a leading role in overall ecosystem productivity.

Conclusion and Discussion

In natural temporary lakes, the structure of biological communities is primarily influenced by the duration of the hydroperiod [19-20]. Additionally, the concentration of dissolved substances and the physicochemical parameters of the water tend to be more stable in lakes with longer hydroperiods [22]. However, in lakes with a controlled hydrological regime, the concentrations of dissolved substances and the physicochemical parameters exhibit low variability, and the hydroperiod does not influence these dynamics.

In temporary water bodies, predation pressure and environmental conditions—determined by hydroperiod duration—are considered the dominant forces shaping zooplankton communities. These two factors exert the strongest influence at both ends of the hydroperiod gradient [7,8]. When examining primary succession in a temporary lake with a controlled hydrological regime, the hydroperiod does not play a role in structuring the zooplankton community. The absence of predation pressure and the relatively stable environmental parameters, maintained by the continuous water flow, create favorable conditions for zooplankton development. As a result, a viable community establishes itself, playing a key role in the ecosystem's productivity. This community is primarily composed of cyclopoid copepods and cladocerans, which are species characterized by wide distribution, short life cycles, and omnivorous feeding habits.

The macrozoobenthic community fails to establish a stable population due to the absence of bottom sediments and organic deposits. As a result, its development is limited to the lake's shoreline, where leaf litter accumulates. Chironomids are the primary colonizers of the benthic zone. Other insect families, which typically constitute a significant component of benthic communities, fail to establish viable populations and are represented by only a few isolated individuals. The lack of a suitable substrate and the short duration of the lake's existence prevent the development of a fully functional macrozoobenthic community, making it entirely dependent on colonization from surrounding areas.

The timing of lake filling is an important factor in community formation. In temporary lakes, particularly those with shorter hydroperiods, the first weeks or months after filling are crucial for species richness [6, María]. Since colonization occurs under different climatic conditions each year, the resulting zooplankton community structure varies accordingly. In 2014, Ariana Lake was filled in mid-June, unlike other years when filling occurred at the end of May. Higher temperatures, lower oxygen concentrations, and elevated pH levels (approximately 8.5) in June significantly influenced the development of copepods and cladocerans [23]. This shift in conditions allowed rotifers to assume a dominant role in the zooplankton community [24]. Thus, in lakes with a controlled hydrological regime, the timing of filling becomes a key factor in determining zooplankton community composition [25].

Regardless of the specific community structure, these assemblages remain species-poor, with high evenness and low dominance. However, the zooplankton community successfully establishes a viable population, playing a significant role in the ecosystem's energy flow. In contrast, the macrozoobenthic community is strongly influenced by the presence of bottom sediments. In natural temporary lakes, lake age is an essential factor shaping macrozoobenthic communities [6]. In the case of Ariana Lake, which is effectively reset to year zero annually, the age of the lake plays a more significant role in determining macrozoobenthic community structure than hydrological stability or predation pressure.

Biotic factors such as competition and predation have less impact on the development of zooplankton and macrozoobenthic communities in temporary water bodies [9]. These findings enhance our understanding of temporary lake ecology and contribute to informed decision-making for biodiversity conservation in such ecosystems [`3].

Appendices

2013	2014	2015
Cyclopoidae sp.	*Acanthocyclops robustus*	*Cyclopoidae* sp.
Acanthocyclops robustus	*Arctodiaptomus pectinicornis*	*Cyclopoidae* sp.
Calanoida sp.	*Daphnia gr. longispina*	*Acanthocyclops robustus*
Daphnia gr. longispina	*Moina rectirostris*	*Thermocyclops dybowskii*
Simocephalus vetulus	*Simocephalus vetulus*	*Metacyclops gracilis*
Chydorus sphaericus	*Graptoleberis testudinaria*	*Daphnia* sp.
Alona rectangula	*Chydorus sphaericus*	*Daphnia gr. longispina*
Alonella sp.	*Euchlanis* sp.	*Ceriodaphnia reticulata*
Lecane sp.	*Trichotria* sp.	*Simocephalus vetulus*
Brachionus sp.		*Graptoleberis testudinaria*
nauplius		*Scapholeberis kingi*
		Euricercus lamelatus
		Chydorus sphaericus
		Alona rectangula
		Pleuroxus aduncus
		Platyias quadricornis
		nauplius

Table 2: List Of Taxa Plankton Found in Lake Ariana During the Years Studied.

2013	2014	2015
Sigara sp.	*Sigara* sp.	*Corixidae* g. sp.
Sigara lateralis	*Sigara lateralis*	*Sigara lateralis*
Cloeon dipterum	*Sigara semistriata*	*Plea minutissima*
Libellulidae	*Cloeon dipterum*	*Cloeon dipterum*
Cricotopus sylvestris	Libellulidae	*Planorbidae* sp.
Chironomus gr. riparius	*Planorbidae* sp.	*Cricotopus sylvestris*
Tanytarsus gregarius	*Cricotopus sylvestris*	*Chironomus gr. riparius*
Cryptochironomus gr. defectus	*Chironomus gr. riparius*	*Tanytarsus gregarius*
Cricotopus sp.	*Cryptochironomus gr. defectus*	*Cryptochironomus gr. defectus*
Tanytarsus sp.	*Diptera* sp.	*Chironomus* sp.
Chaoborus sp.	*Hydracarina* sp.	*Cricotopus* sp.
Nais communis		*Tanytarsus* sp.
Nais pardalis		*Criptochironomus* sp.
		Tvetenia sp.

Table 3: List Of Taxa Benthos Found in Lake Ariana During the Years Studied.

Conflict Of Interest: The authors declare that they have no actual, potential, or perceived conflict of interest for this article.

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